FLIGHT DYNAMIC AND CONTROL FINAL REPORT

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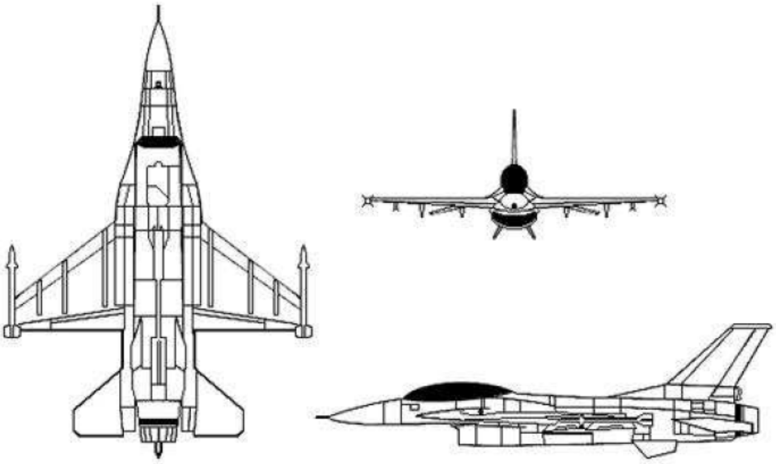
INTRODUCTION



Parameter	Symbol	Value
aircraft mass (kg)	m	9295.44
reference wing span (m)	b	9.144
reference wing area (m^2)	S	27.87
mean aerodynamic chord (m)	$\bar{c}$	3.45
roll moment of inertia (kg.m^2)	I_x	12874.8
pitch moment of inertia (kg.m^2)	I_y	75673.6
yaw moment of inertia (kg.m^2)	I_z	85552.1
product moment of inertia (kg.m^2)	I_{xz}	1331.4
product moment of inertia (kg.m^2)	I_{xy}	0.0
product moment of inertia (kg.m^2)	I_{yz}	0.0
c.g. location (m)	x_{cg}	$0.3\bar{c}$
reference c.g. location (m)	x_{cg_r}	$0.35\bar{c}$
engine angular momentum (kg.m^2/s)	h_E	216.9

Nominal Condition: $h = 0$ ft, $\overline{q} = 300$ psf, $Xcg = .35\overline{c}$, $\dot{\phi} = \dot{\theta} = \dot{\psi} = \gamma = 0$

variable	CONDITION Nominal	$Xcg = 0.3\overline{c}$	$Xcg = +0.38\overline{c}$	$Xcg = +0.3\overline{c}$ $\dot{\psi} = 0.3$ r/s	$Xcg = -0.3\overline{c}$ $\dot{\theta} = 0.3$ r/s
V_T (ft/s)	502.0	502.0	502.0	502.0	502.0
α (rad)	0.03691	0.03936	0.03544	0.2485	0.3006
β (rad)	−4.0E-9	4.1E-9	3.1E-8	4.8E-4	4.1E-5
ϕ (rad)	0	0	0	1.367	0
θ (rad)	0.03691	0.03936	0.03544	0.05185	0.3006
P (r/s)	0	0	0	−0.01555	0
Q (r/s)	0	0	0	0.2934	0.3000
R (r/s)	0	0	0	0.06071	0
THTL(0-1)	0.1385	0.1485	0.1325	0.8499	1.023
EL(deg)	−0.7588	−1.931	−0.05590	−6.256	−7.082
AIL(deg)	−1.2E-7	−7.0E-8	−5.1E-7	0.09891	−6.2E-4
RDR(deg)	6.2E-7	8.3E-7	4.3E-6	−0.4218	0.01655

Mass and Geometric parameters

Accpetable values for flight condition parameters are:

Variable	Units	Model LOFI Min	Max	HIFI Min	Max
Altitude:	ft	5000	40000	5000	40000
AOA	deg	-10	45	-10	90
Thrust	lbs	1000	19000	1000	19000
Elevator	deg	-25.0	25.0	-25.0	25.0
Aileron	deg	-21.5	21.5	-21.5	21.5
Rudder	deg	-30	30	-30	30
Velocity	ft/s	300	900	300	900

I. COMPUTATION AND ANALYZE OF F-16 LONGITUDINAL DYNAMICS SYSTEM

1. ANALYZE LONGITUDINAL MODES

Running **FindDynamics** will give the state space matrices (A, B, C, and D) for both the longitudinal and lateral directions. The states for the longitudinal modes are altitude, pitch angle, magnitude of the total velocity angle of attack and pitch rate. The control inputs are thrust and elevator deflection. It also find the poles and the corresponding damping ratio and the natural frequency for each mode

The longitudinal state-space matrices given by FindF16Dynamics will be of the from.

$$\begin{bmatrix} \dot{h} \\ \dot{\theta} \\ \dot{v} \\ \dot{\alpha} \\ \dot{q} \\ \dot{\delta_t} \\ \dot{\delta_e} \end{bmatrix} = \mathbf{A} \begin{bmatrix} h \\ \theta \\ v \\ \alpha \\ q \\ \delta_t \\ \delta_e \end{bmatrix} + \mathbf{B} \begin{bmatrix} \delta_t \\ \delta_e \end{bmatrix}$$

$$\begin{bmatrix} h \\ \theta \\ v \\ \alpha \\ q \end{bmatrix} = \mathbf{C} \begin{bmatrix} h \\ \theta \\ v \\ \alpha \\ q \end{bmatrix} + \mathbf{D} \begin{bmatrix} \delta_t \\ \delta_e \end{bmatrix}$$

Here we will only show the result that concerning Longitudinal directional modes.

```
Altitude: 10000.000 ft.
Velocity: 600.000 ft/s


For HIFI Model:
Longitudal Direction:


A =
   0.000e+00    6.000e+02    0.000e+00   -6.000e+02    0.000e+00    0.000e+00    0.000e+00
   0.000e+00    0.000e+00    0.000e+00    0.000e+00    1.000e+00    0.000e+00    0.000e+00
   1.145e-04   -3.217e+01   -1.220e-02    1.312e+01   -5.676e-01    1.569e-03    1.313e-01
   1.671e-06   -7.391e-14   -1.780e-04   -9.427e-01    9.298e-01   -9.435e-08   -2.127e-03
   5.274e-12    0.000e+00   -5.616e-10   -7.625e-01   -1.223e+00    0.000e+00   -2.038e-01
   0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00   -1.000e+00    0.000e+00
   0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00   -2.020e+01
B =
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   1.000e+00    0.000e+00
   0.000e+00    2.020e+01
```

```
C =
   1.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00
   0.000e+00    5.730e+01    0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00
   0.000e+00    0.000e+00    1.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00
   0.000e+00    0.000e+00    0.000e+00    5.730e+01    0.000e+00    0.000e+00    0.000e+00
   0.000e+00    0.000e+00    0.000e+00    0.000e+00    5.730e+01    0.000e+00    0.000e+00
D =
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00

      real       imaginary      frequency      damping

   1.6237e-07    0.0000e+00    1.6237e-07   -1.0000e+00
  -5.6052e-03   -5.2158e-02    5.2458e-02    1.0685e-01
  -5.6052e-03    5.2158e-02    5.2458e-02    1.0685e-01
  -1.0000e+00    0.0000e+00    1.0000e+00    1.0000e+00
  -1.0832e+00   -8.3123e-01    1.3653e+00    7.9332e-01
  -1.0832e+00    8.3123e-01    1.3653e+00    7.9332e-01
  -2.0200e+01    0.0000e+00    2.0200e+01    1.0000e+00

For LOFI Model:
Longitudal Direction:


A =
   0.000e+00    6.000e+02    0.000e+00   -6.000e+02    0.000e+00    0.000e+00    0.000e+00
   0.000e+00    0.000e+00    0.000e+00    0.000e+00    1.000e+00    0.000e+00    0.000e+00
   1.804e-04   -3.217e+01   -1.921e-02    1.115e+02    3.164e+00    1.565e-03    3.163e-01
  -1.713e-06    6.413e-13    5.190e-07   -9.675e-01    9.393e-01    2.144e-07   -1.851e-03
   3.551e-06    0.000e+00   -3.781e-04   -1.236e+00   -3.850e-01    0.000e+00   -1.648e-01
   0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00   -1.000e+00    0.000e+00
   0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00   -2.020e+01
B =
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   1.000e+00    0.000e+00
   0.000e+00    2.020e+01
```

```
C =
   1.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00
   0.000e+00    5.730e+01    0.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00
   0.000e+00    0.000e+00    1.000e+00    0.000e+00    0.000e+00    0.000e+00    0.000e+00
   0.000e+00    0.000e+00    0.000e+00    5.730e+01    0.000e+00    0.000e+00    0.000e+00
   0.000e+00    0.000e+00    0.000e+00    0.000e+00    5.730e+01    0.000e+00    0.000e+00
D =
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00
   0.000e+00    0.000e+00

     real        imaginary      frequency      damping

  -3.5942e-03    0.0000e+00    3.5942e-03    1.0000e+00
   8.1434e-02    0.0000e+00    8.1434e-02   -1.0000e+00
  -1.2479e-01    0.0000e+00    1.2479e-01    1.0000e+00
  -1.0000e+00    0.0000e+00    1.0000e+00    1.0000e+00
  -6.6241e-01   -1.0337e+00    1.2278e+00    5.3953e-01
  -6.6241e-01    1.0337e+00    1.2278e+00    5.3953e-01
  -2.0200e+01    0.0000e+00    2.0200e+01    1.0000e+00
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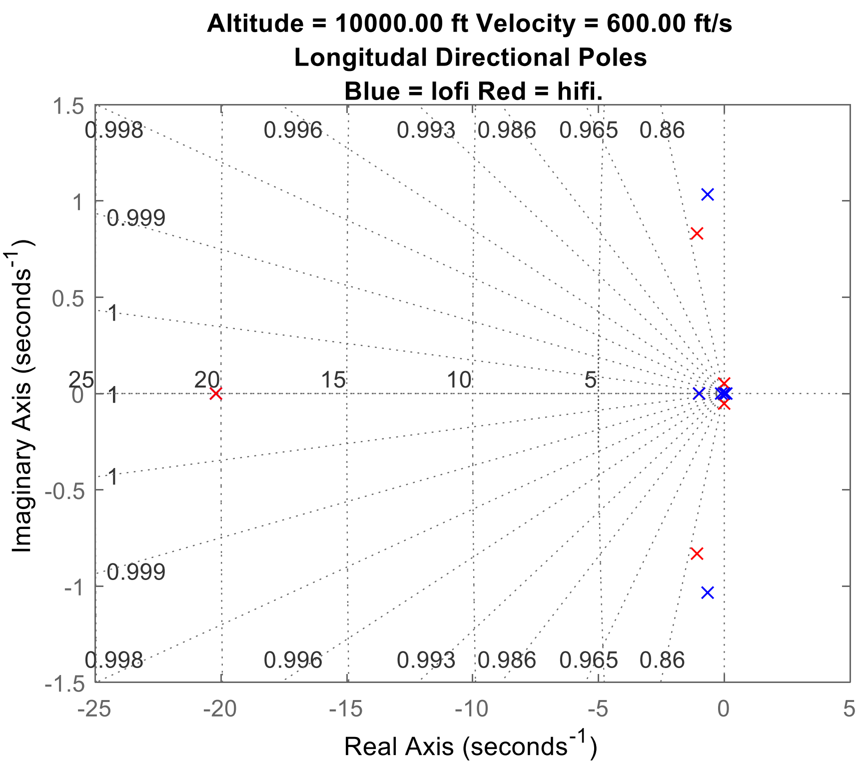
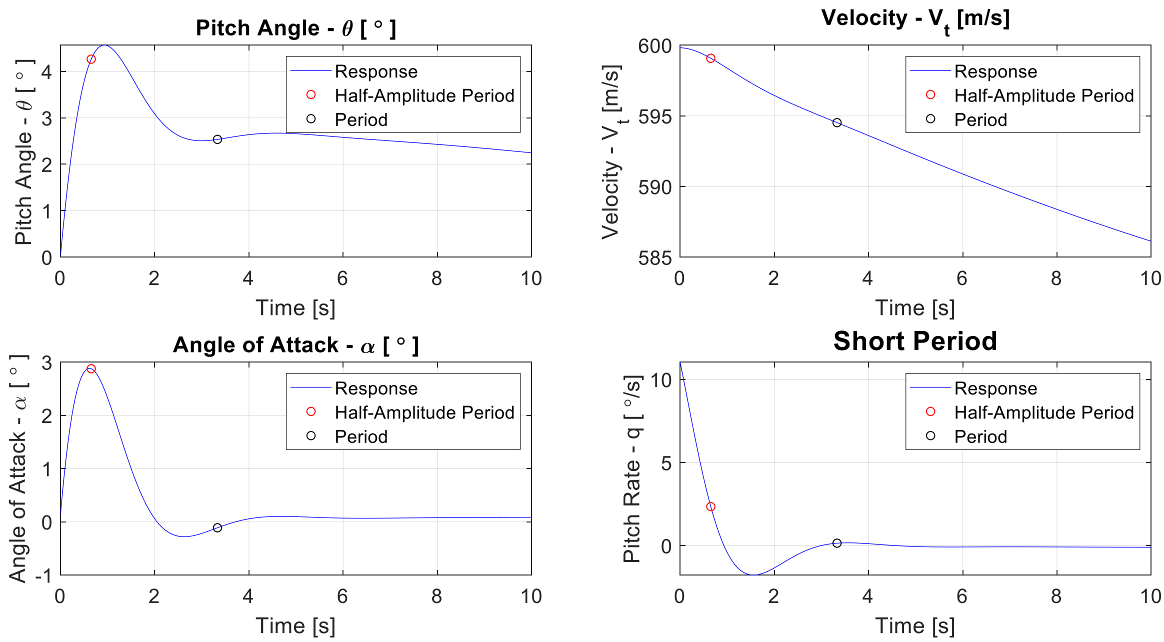


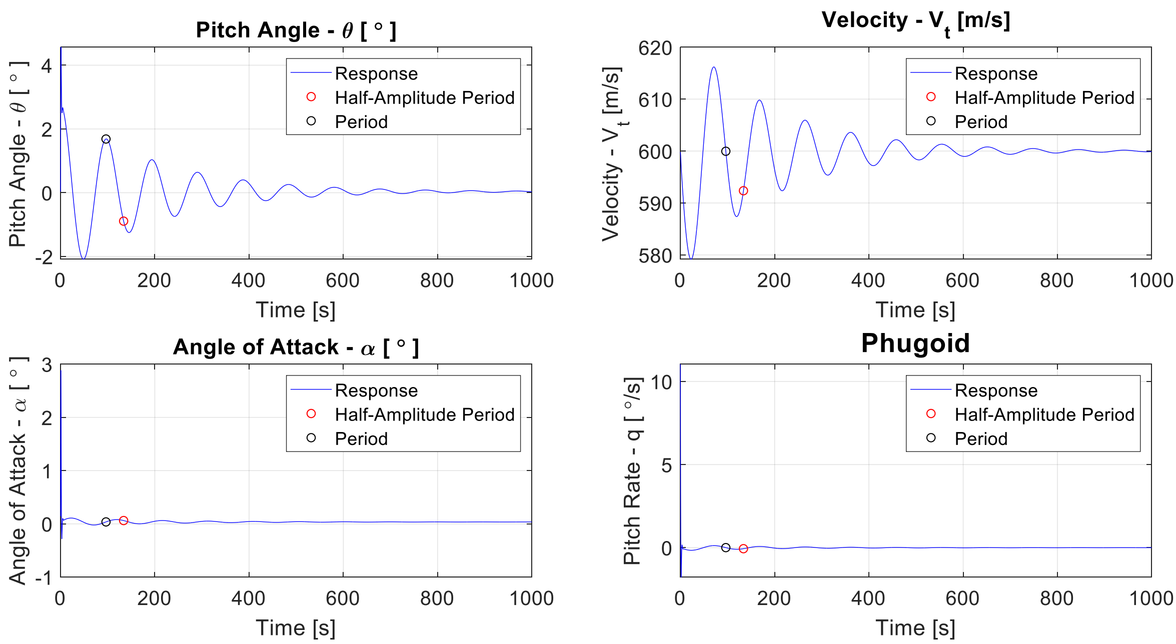
The longitudinal Bode plot will be display in the following order

Plot #	State	Input
1	h	δ_t
2	h	δ_e
3	θ	δ_t
4	θ	δ_e
5	v	δ_t
6	v	δ_e
7	α	δ_t
8	α	δ_e
9	q	δ_t
10	q	δ_e

Table 5. Longitudinal Bode Plots.

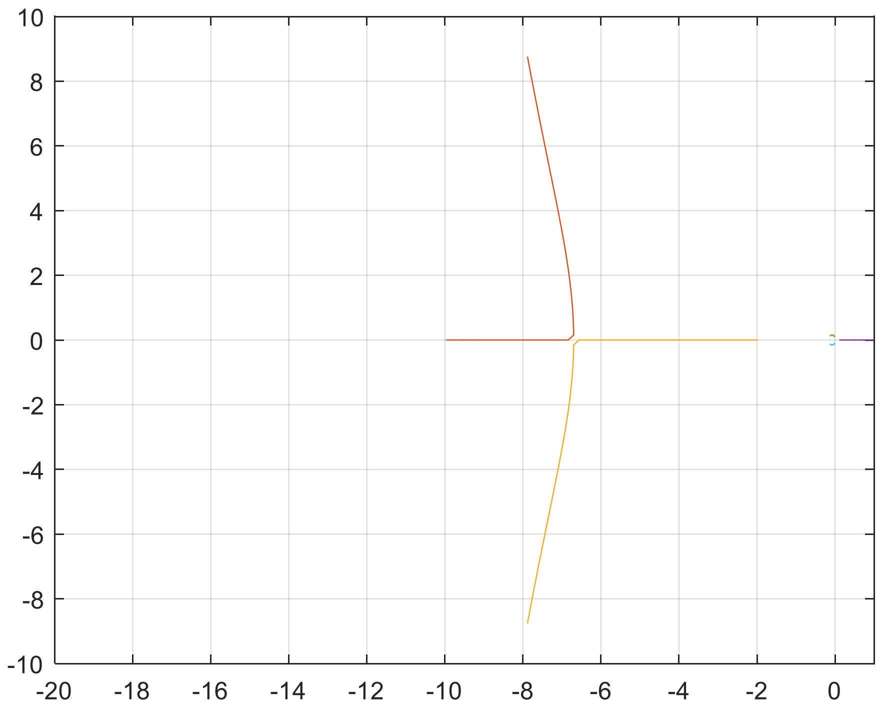
After we found the matrices, we should reduce them to the familiar flight dynamics form of the fourth order. Then we can calculate the motion characteristics of the open loop model. These characteristics show the inherent flying quality of the aircraft.
In the matlab File timeResponse you will find the code that produce the open loop response to step input. For both the short period and the fugoid period.

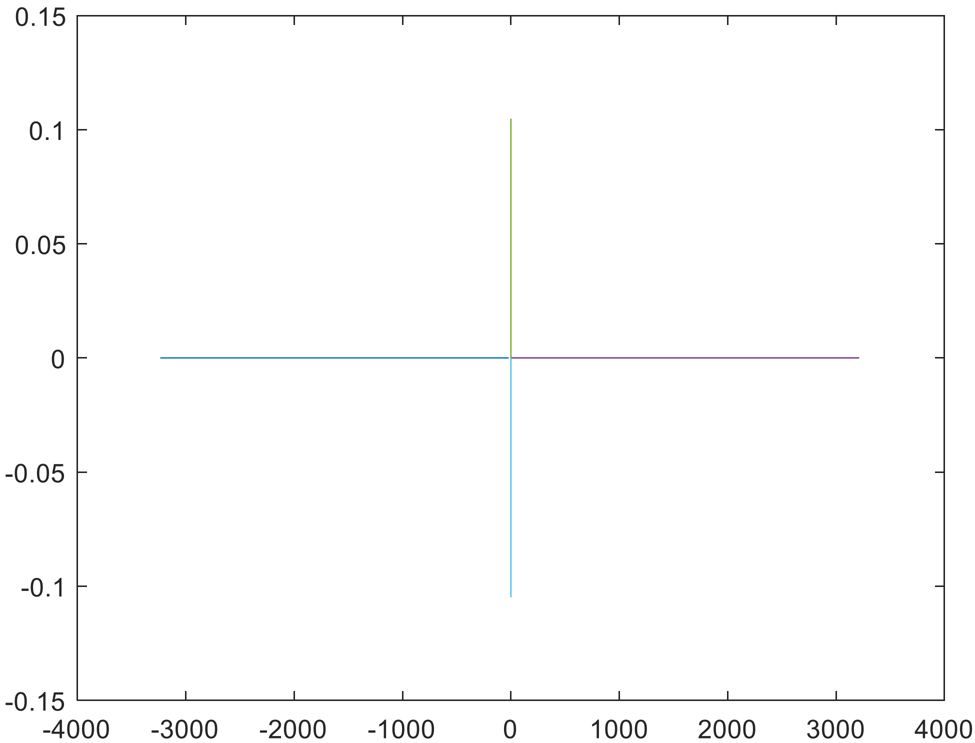




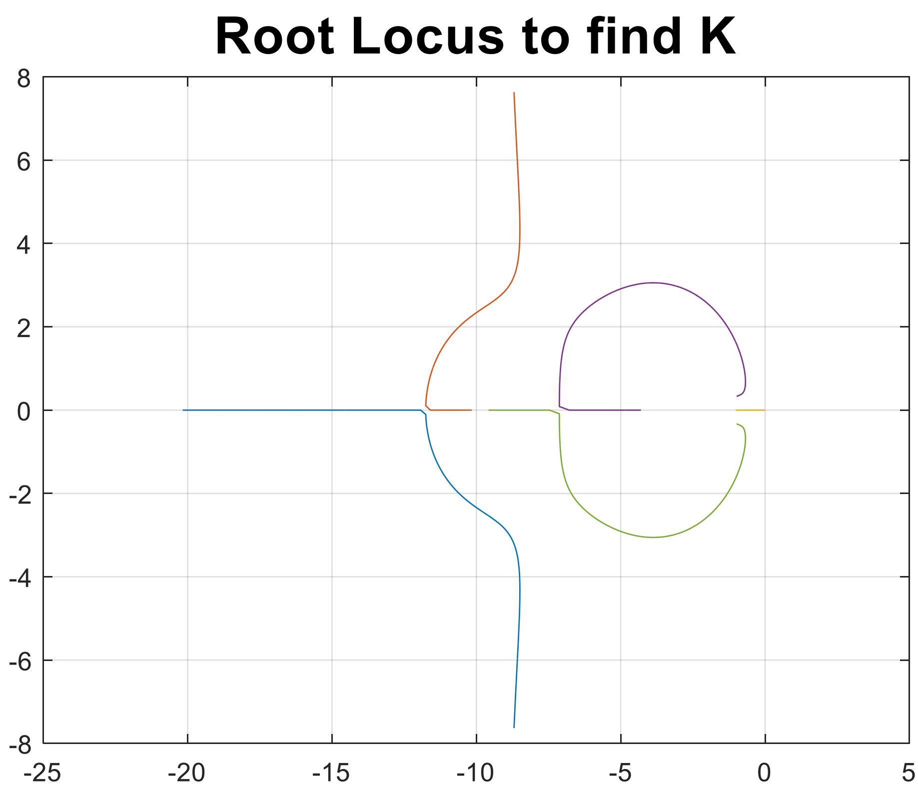
II. DESIGN AUTOMATIC FLIGHT CONTROL SYSTEM

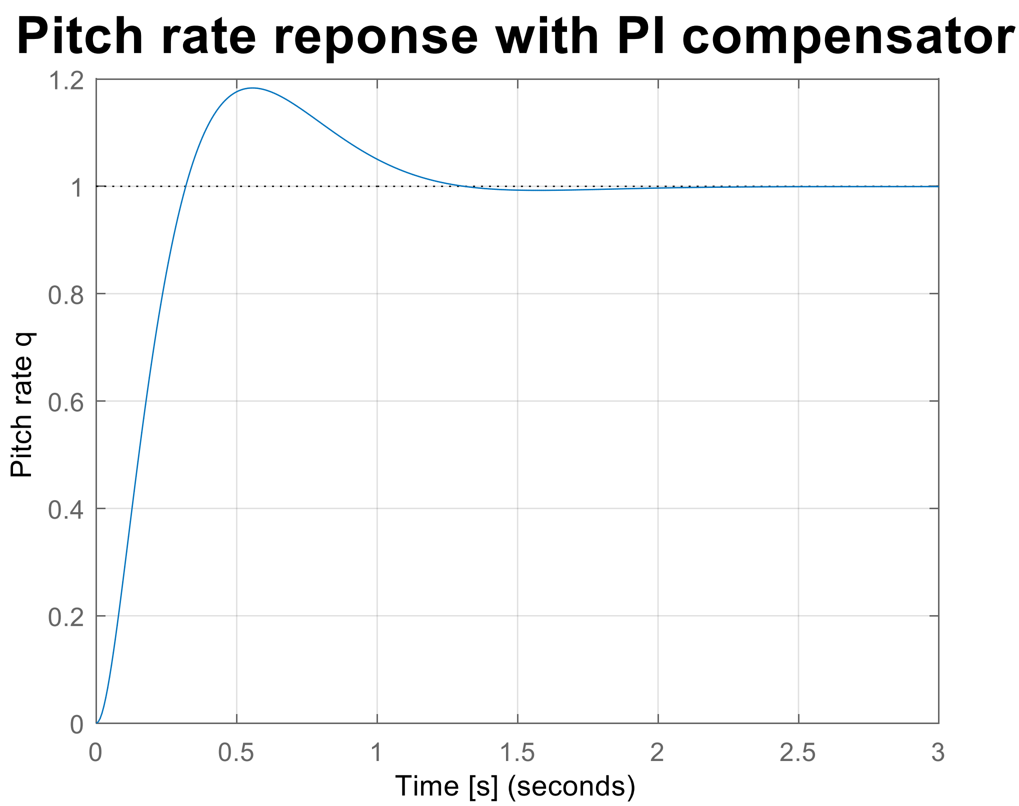
In the design of the controller only short period counts.
In the following section, we will use the Jacobian matrix for F-16 model in the nominal flight condition.
Then we write the augmented matrix directly in the workspace. Then we can apply the rlocus matlab function to find the proper value for kα.
Run the file rlocus1 then rlocus2 compare and and choose the appropriate coefficients.





In the matlab file CAS.m you will find the complete control augmented system, with stability augmented.





In conclusion, we can say that the PI compensator is enough to control the short period pitch rate.

CONCLUSION

This course of Flight dynamic was very challenging but very instructive for us. After tremendous research and reading on the subject, we have managed to understand all the basic concerning the subject. The teaching methods and evaluation method was perfectly adapted to the current situation we are living with Covid19. Thank you professor, I am eager to learn more from you.